Antarctic Pack Ice Seals:

INDICATORS OF ENVIRONMENTAL CHANGE AND CONTRIBUTORS TO CARBON FLUX

An international research program coordinated by the SCAR Group of Specialists on Seals

Antarctic
Pack
Ice
Seals

APIS Program

INTRODUCTION

The pack ice region surrounding Antarctica contains at least 50% of the world's population of seals, with population levels comprising about 80% of the world's total pinniped biomass (Laws 1984). These seals are among the dominant top predators in Southern Ocean ecosystems and the fluctuations in their populations, patterns of growth, and life histories (e.g., Bengtson & Laws 1985; Testa et al. 1991) provide a potential source of information about environmental variability integrated over a wide range of spatial and temporal scales. As top predators, seals are likely to be sensitive to changes in the dynamics of ecosystems and, in particular, variations in the flux of photosynthetically-fixed carbon to higher levels of the food chain caused by either climatic or ecological changes.

Of the six species of Antarctic pinnipeds, three inhabit the pack ice region year-round: crabeater seals (*Lobodon carcinophagus*), leopard seals (*Hydrurga leptonyx*), and Ross seals (*Ommatophoca rossii*). Of all of the Antarctic seals, crabeater seals are by far the most numerous. Weddell seals (*Leptonychotes weddellii*) normally breed on shore-fast ice habitats, but also spend major portions of the year in the pack ice zone. Whereas southern elephant seals (*Mirounga leonina*) had previously been thought to occupy ice-free waters within range of their subantarctic breeding islands, recent studies have shown that they, too, are spending time in pack ice habitats (McConnell et al. 1992; Hindell et al. 1991). Although Antarctic fur seals (*Arctocephalus gazella*), which breed on land, have been observed in the marginal ice zone (e.g., Fraser et al. 1989), they are believed to spend most of their time in open-water habitats north of the pack ice.

The very high abundance of seals and other air-breathing predators in the Southern Ocean, in relation to primary production, may be unique in global terms. This high tertiary production suggests unusual ecosystem processes and, because of their position at the top of food chains and their abundance, these seals provide a window through which large-, meso- and fine-scale ecological variability can be studied in both geographical and temporal terms.

In order to assess their functional significance in Southern Ocean ecosystems, a greater understanding is needed of:

1) seals' roles in ecosystem processes, through trends in population parameters, physiological condition, and behavior; and

2) seals as processors of carbon, including sources of carbon used (both metabolic substances and prey), the turn-over rate of carbon, and eventual deposition sites (e.g., respired to the atmosphere or returned to the system via the microbial loop).

In addition to their potential significance in carbon flux systems, seals integrate environmental variability over a wide range of geographical and temporal scales. As long-lived mammals with large body size and low reproductive rates, some aspects of their biology, such as population age structures and patterns of growth (e.g., Testa et al. 1991; Boyd & Roberts 1992), are buffered against short-term or local environmental variation. Because pack ice seals are obligate inhabitants throughout the seasonal ice zone, these seals are excellent indicators of large scale environmental change in both temporal (decades) and spatial (regional) terms. On a smaller scale, variations in seal distribution, abundance and features of their behavior and physiology in different localities, in different years and seasons, can provide valuable insights into changes in oceanographic features, such as the locations of frontal zones and areas of high secondary production.

These aspects have significance not only to our ecological understanding of the seals themselves but could provide unique opportunities for further understanding of oceanographic features beneath the pack ice (i.e., where it is difficult to make oceanographic measurements). For example, recent advances in technology allow studies of seal behavior and environmental conditions within the ice-covered water column. Additional technology is becoming available so that the pack ice seals could be used as free-ranging platforms for oceanographic instruments to record and relay data on sea temperature, conductivity, and ambient light at depth.

Products to Antarctic research programs and intergovernmental organizations

The Group of Specialists on Seals, of the Scientific Committee on Antarctic Research (SCAR), is charged with reviewing the status of stocks, encouraging and coordinating scientific research on Antarctic pinnipeds, and providing scientific advice and recommendations to SCAR and other international organizations. Recognizing the important need for a better understanding of the pack ice seals and the role that they play in the Antarctic marine ecosystem, the Group of Specialists on Seals has recommended that a coordinated, multi-national research initiative be developed: the Antarctic Pack Ice Seals (APIS) Program.

The APIS Program will produce information of value to several Antarctic research programs and intergovernmental organizations. A number of these research initiatives have begun in recent years, or will soon be initiated under the auspices of SCAR, the Scientific Committee for Oceanic Research (SCOR), or other bodies. Many features of Antarctic natural systems are being investigated such as biogeochemical cycles, climatology, oceanography, marine ecology, and have focused on obtaining a better understanding of global environmental change. As concern about possible global change and man's potential impacts in the Antarctic has increased, there has been a growing need for information about diverse aspects of Antarctic ecosystems. The APIS Program will complement these programs by providing essential information on an important upper trophic level component of the Antarctic marine ecosystem. Some of these programs, and the expected contributions to them from the APIS Program, are described below.

CCAMLR Ecosystem Monitoring Program (CEMP)

The CCAMLR Ecosystem Monitoring Program (CEMP) is designed to detect significant changes in key components of the Southern Ocean ecosystem and to distinguish between changes due to commercial harvesting of marine living resources and those due to natural causes. These objectives reflect a practical strategy to attempt to implement the conservation principles set down in Article II of the CCAMLR Convention (i.e., that management of Antarctic marine living resources should be carried out within an ecosystem perspective). It was recognized that it was not feasible to attempt monitoring the status of all marine organisms and their interactions to give effect to these principles. As a practical alternative, it was agreed that representative species and parameters, especially those thought to be sensitive to changes in food availability or environmental changes, should be monitored to provide assessments of potential changes occurring in the marine ecosystem. CEMP activities are well underway for collecting and analyzing data for predators in ice-free areas (selected seabird and land-breeding pinnipeds), their prey, and environmental conditions. Crabeater seals have also been identified by CEMP as a priority species for monitoring; however, implementation of CEMP activities in the pack ice zone has not advanced very far due to limited availability of logistic and financial support. It is expected that the pack ice seal research outlined in this prospectus would represent a major contribution to CEMP.

Joint Global Ocean Flux Study (JGOFS)

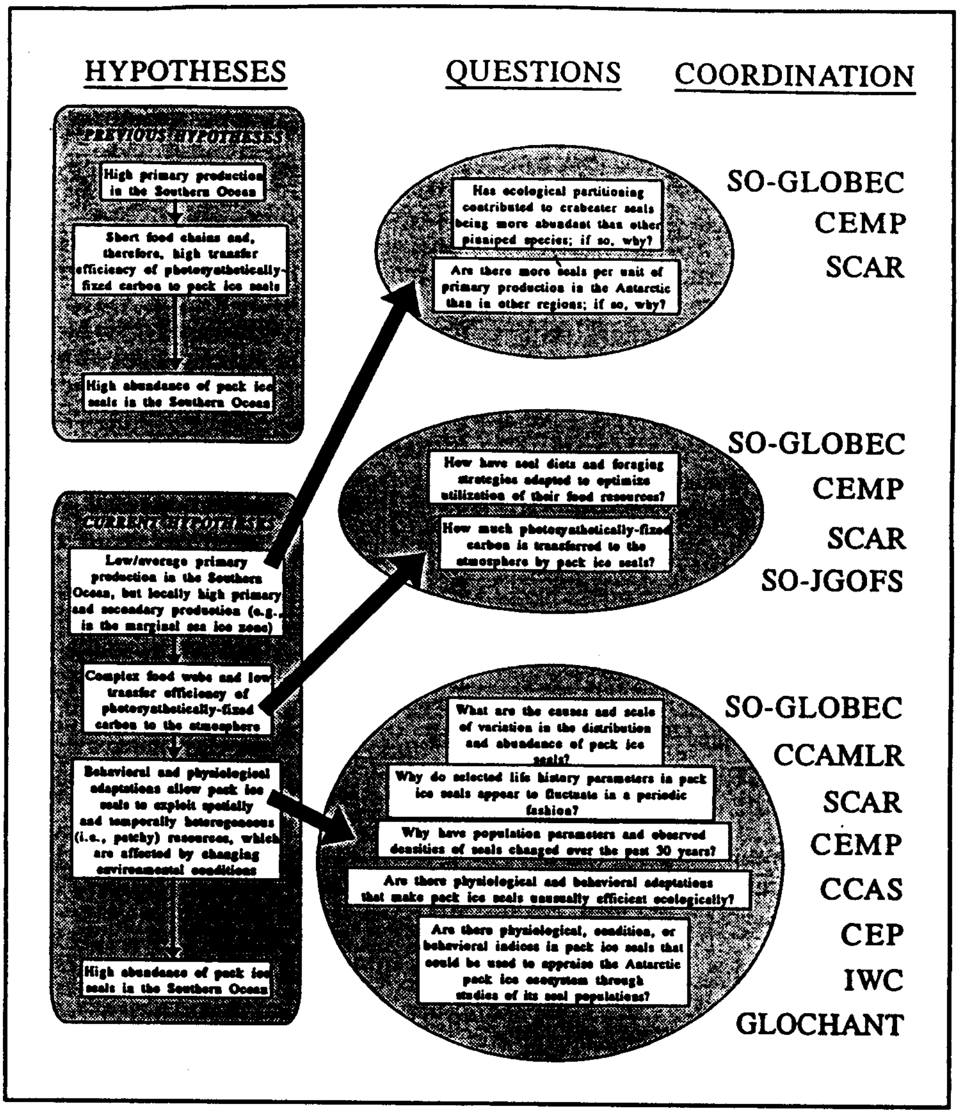
The Southern Ocean Joint Global Ocean Flux Study (SO-JGOFS) was established by SCOR to examine the dynamics of physical and biogeochemical processes in the Southern Ocean. The program was designed to address the significance of these processes to global change; this program is one of the core projects of the International Geosphere Biosphere Program (IGBP) of the International Council of Scientific Unions (ICSU). SO-JGOFS will provide fundamental information about carbon flux and sequestration within the Southern Ocean, but is targeted mainly at lower trophic levels to develop an understanding of the physical and chemical constraints on primary production. The APIS Program will complement SO-JGOFS by providing information about carbon flux at upper trophic levels of the ecosystem as well as the long-term and short-term variability in ecosystem dynamics. Information about the magnitude and patterns of small- and meso-scale temporal and geographical variability in primary production, which is likely to emerge from SO-JGOFS, will be important to the interpretation of data on ice seal biology. Longer-term data will also be available on ecosystem dynamics because seal populations integrate processes over longer time scales than are normally possible with either ship-board investigations or from data obtained via remote sensing. This feature of pack ice seal studies can be used to help provide a broader context for the small- and meso-scale data emerging from SO-JGOFS.

Southern Ocean Global Ecosystem Dynamics (SO-GLOBEC)

Southern Ocean Global Ecosystem Dynamics (SO-GLOBEC) is an international research program being developed under the auspices of SCOR and SCAR to address the issue of the significance of Southern Ocean ecosystem dynamics in relation to global change. SO-GLOBEC is complementary to SO-JGOFS because it is concerned with all trophic levels of the ecosystem, including the top predators. Crabeater seals, as well as leopard seals, have been identified as being priority species to be studied within the SO-GLOBEC program. Although the SCAR pack ice seal program is independent of SO-GLOBEC, it would seem desirable to develop its planned seal research in close coordination with SO-GLOBEC, thereby providing assistance to SO-GLOBEC in its desire to include pack ice seals in its investigations.

Global Change and the Antarctic (GLOCHANT)

SCAR has recently established a new Group of Specialists to initiate and coordinate a major program on Global Change and the Antarctic (GLOCHANT), which may also become an Antarctic regional contribution to the IGBP. It is planned to run for 10 years with a review point after 5 years. The planning structure consists of the Group of Specialists itself and 7 working groups responsible for 5 core scientific



programs, modeling and data management. Each of the 5 core program working parties will include a representative of the Council of Managers for National Antarctic Programs (COMNAP), to facilitate consideration of logistic needs. One of the core projects focuses on the Antarctic Sea Ice zone. A further core program "Detection of Change" will be addressed by all five scientific program groups. The APIS Program will therefore be very relevant to GLOCHANT activities, and coordination of seal research initiatives within both GLOCHANT and COMNAP will be important.

Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR)

In addition to initiatives through its Working Group for CEMP, the CCAMLR Scientific Committee maintains a strong interest in the status and trends of pinniped populations throughout the Antarctic. At its meetings during the past several years, the Scientific Committee noted that because recent census data for pack ice seals were unavailable, it was not possible to determine to what extent crabeater seals may have undergone a dramatic population decline during the 1970's. The Scientific Committee had therefore urged national programs to conduct censuses of seals in pack ice areas when opportunities arose to conduct such surveys from icebreakers. At its 1992 meeting, the Scientific Committee welcomed the SCAR pack ice seal research initiative, and agreed that the information expected from it would provide valuable information of relevance not only to CCAMLR's interest in the status and trends of Antarctic pinniped populations, but also to the work of CEMP. CCAMLR encouraged its members to accord a high priority to having their scientists participate in the SCAR pack ice seal research program, and to allocate sufficient financial and logistic support to enable the ice seal initiative to succeed.

Committee for Environmental Protection (CEP)

A Protocol on Environmental Protection was agreed under the Antarctic Treaty in Madrid in 1991, designating Antarctica as "a natural reserve, devoted to peace and science". It provides a set of environmental principles to govern human activities as well as specifying measures to determine the degree of impact from such activities. Further, it establishes a Committee for Environmental Protection (CEP) as an expert body to provide advice. Considering the pack ice seals' role as indicators of ecosystem status and environmental change, it is expected that the APIS Program will contribute valuable information to CEP once that committee is formed.

Convention for the Conservation of Antarctic Seals (CCAS)

The Convention for the Conservation of Antarctic Seals (CCAS), which came into force in 1978, invited SCAR to assume responsibility for providing scientific advice, including recommendation of programs for scientific research and reporting on the status of the Antarctic seal stocks in relation to ecological systems. SCAR accepted that formal responsibility and has provided advice over the years, including a detailed report to the meeting held in 1988 to review the operation of CCAS. Since 1983, the Group of Specialists on Seals has repeatedly drawn attention to the fact that current knowledge of the status of pack ice seal populations is based on past surveys carried out in 1968 to 1983; no comprehensive surveys have been carried out since 1983. Furthermore, re-analyses of the earlier data suggested a disturbing decline in observed seal densities between 1968 and 1983. Subsequently, the 1988 meeting reviewing CCAS endorsed the recommendations that further work on pack ice seals be undertaken as a matter of priority. The research program outlined in this prospectus will provide this much-needed information.

International Whaling Commission (IWC)

Crabeater seals occupy a similar trophic position in the Antarctic marine ecosystem to that of some species of baleen whales. A major current objective of the Scientific Committee of the IWC is to understand the factors influencing the abundance and distribution of these whales, and to promote the recovery of depleted baleen whale stocks. The extent to which changes in the Antarctic marine environment or competition among depleted whale stocks and other top predators may be affecting the whales' recovery is unknown. Seals and whales overlap during the austral summer in the marginal ice zone and interact within elements of the same ecosystem. Studies of the relationship of environmental and biotic features of the pack ice ecosystem, including the seals, will yield information relevant to understanding the foraging behavior, ecology, and life history of other predators such as whales. In this way, it is anticipated that the pack ice seal research program will contribute to helping achieve some of the IWC's objectives.

PRIORITY QUESTIONS

Within the context of a coordinated multinational research program addressing the role of seals in the Southern Ocean pack ice environment, several areas of research are closely-linked or are inter-dependent with one another. In the following section, these areas of research have been formulated as questions posed to address hypotheses regarding seals' roles in the pack ice ecosystem. The interactions between the major questions and related research activities are indicated in Table 1. The anticipated relevance of the products arising from each question of interest to other research programs or intergovernmental organizations is also shown.

1. What are the causes and scale of variation in the distribution and abundance of pack ice seals?

Research is needed to explore the temporal and spatial variability in seal abundance and distribution and their relationships to prey availability, human activities, and climatic and oceanographic changes. The biology of pack ice seals in the Antarctic is intimately linked to the extent and type of the sea ice environment, which exhibits both seasonal and inter-annual variability. Seals' spatial partitioning of the pack ice environment demonstrates distribution patterns which need to be better understood to evaluate the seals' role in these ecosystems and the potential impacts of environmental change; crabeater and leopard seals are often present in the marginal ice zone, Ross seals in mid-pack and Weddell seals on near-shore ice.

2. Has ecological partitioning contributed to crabeater seals being more abundant than other species; if so, why?

Current best estimates indicate that the crabeater seal (c. 15 million) is the most abundant Antarctic seal by orders of magnitude. Ecological partitioning is related to diet and foraging behavior, and is dependent on latitude, foraging depth range, underlying sea floor (shelf, shelf edge, deep basin), and morphological adaptations for prey selection. These differences are reflected in seal diets: crabeater seals feed virtually exclusively on krill; southern elephant and Ross seals consume cephalopods in deep water; Weddell seals feed on fish and squid over the shelf; and leopard seals eat all these diet items plus birds and other seals. The crabeater seal, which is the most restricted in its diet, exploits a locally abundant and spatially heterogeneous food resource at a low trophic level. This relationship is unusual ecologically and merits further research.

3. Are there more seals per unit of primary production in the Antarctic than in other regions; if so, why?

In a global comparison, Southern Ocean primary productivity is not as high as previously thought. Total annual primary production from the Southern Ocean (1.23 Gtonnes C per year) is now estimated to be <5% of the global total (27.2 Gtonnes C per year) even though the Southern Ocean accounts for about 10% of the global oceanic area (Smith 1991). The prominent position which seals occupy in the Southern Ocean ecosystem had been attributed to high productivity of the ecosystem or short food chains which release energy and photosynthetically-fixed carbon to higher predators with relatively little loss of efficiency (e.g., Laws 1977; Everson 1984). However, in addition to evidence for lower overall primary productivity, there is also increasing evidence for complexity, rather than simplicity, in Antarctic marine food webs (Murphy et al. 1988; Priddle et al. 1992). These characteristics and the presence of very high numbers of seals point to the unusual nature of the Southern Ocean ecosystem on a large scale. However, due to the ecological heterogeneity in the pack ice region at smaller scales, the number of seals per unit of primary production may be more similar to that of other oceanic regions.

4. Why do selected life history parameters in pack ice seals appear to fluctuate in a periodic fashion?

Temporal variation in the relative strength of crabeater seal cohorts and in the abundance of leopard seals at the periphery of their range have been observed and may occur in a periodic fashion (Laws 1984; Testa et al. 1991). The underlying cause for this, and similar fluctuations in Weddell seal reproduction in near-shore areas, is a matter of some speculation. These short-term fluctuations in seal population parameters may have value in understanding possible links between Antarctic climate and global climatic fluctuations such as El Niño-Southern Oscillation events. Furthermore, short-term variability must be understood in order to assess possible long-term trends arising from global warming or increasing ultraviolet radiation.

5. Why have population parameters and observed densities of seals changed over the past 30 years?

A great deal of interest has focused on observed changes in populations of krill predators in the Southern Ocean that have occurred over the past several decades. Crabeater seal age at sexual maturity has been increasing since the 1960's (Bengtson & Laws 1985) and observed densities of crabeater seals in the pack ice appear to have declined between the late 1960's and the early 1980's (Erickson & Hanson 1990). Although there have been several hypotheses concerning the causes of these changes (e.g., reduction of competition following the massive removal of the large baleen whales, or changes in climate and sea ice patterns), our understanding of the population dynamics of crabeater seals and factors affecting those dynamics is incomplete. Interdisciplinary research is required to investigate the underlying causes and the meaning of these population changes in relation to ecosystem interactions and environmental change.

6. How have seal diets and foraging strategies adapted to optimize utilization of their food resources?

Environmental heterogeneity, associated primarily with the sea ice zone (Eicken 1992), can lead to localized areas of high primary production. For example the marginal ice zone may account for as much as 40% of the Southern Ocean's

Table 1. Principal field research activities required to address priority topics. Intergovernmental organizations and other international research programs that are thought likely to benefit from the data acquired through the seal research activities are indicated. CCAMLR=Convention for the Conservation of Antarctic Marine Living Resources; CEP=Antarctic Treaty Committee for Environmental Protection; CCAS=Convention for the Conservation of Antarctic Seals; IWC=International Whaling Commission; SOGLOBEC= Southern Ocean Global Ecosystem Dynamics; SOJGOFS=Southern Ocean Joint Global Ocean Flux Studies; CEMP=CCAMLR Ecosystem Monitoring Program; GLOCHANT=SCAR Global Change and the Antarctic Program.

Research questions	Seal research activities									Seal research will contribute to: Intergovernmental activities				Seal research will contribute to: Research programs			
	Distribution, abundance	Genetics	Habitat use, movements	Platforms for oceanography	Populations dynamics	Diving, feeding behavior	Diet	Energetics, physiology	Toxicology, disease	CCAMLR	CEP	CCAS	IWC	SOGLOBEC	SOJGOFS	CEMP	GLOCHANT
What are the causes and scale of variation in the distribution and abundance of pack ice seals?	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
Has ecological partitioning contributed to crabeater seals being more abundant than other pinniped species; if so, why?	X		X	X	X	X	X	X		X		X		X		X	
Are there more seals per unit of primary production in the Antarctic than in other regions; if so, why?	X		X	X	X	X		X		X	X	X	X	X	X	X	
Why do selected life history parameters in pack ice seals appear to fluctuate in a periodic fashion?	X		X		X	X	X		X	X	X	X	X	X	X	X	X
Why have population parameters and observed densities of seals changed over the past 30 years?	X				X				X	X	X	X	X	X		X	X
How have seal diets and foraging strategies adapted to optimize utilization of their food resources?	X		X			X	X	X		X		X	X	X		X	
Are there physiological and behavioral adaptations that make pack ice seals unusually efficient ecologically?				X		X	X	X		X		X		X		X	
How much photosynthetically-fixed carbon is transferred to the atmosphere by pack ice seals?	X		X		X	X		X						X	X		X
Are there physiological, condition, or behavioral indices in pack ice seals that could be used to appraise the Antarctic pack ice ecosystem through studies of its seal populations?	X		X		X	X	X	X	X	X	X	X	X	X		X	X

total primary production. Seals are highly mobile predators with the capability of rapidly detecting and exploiting food patches. The apparent unusually high abundance of upper trophic level predators such as seals may be more closely allied to the patchiness of food resources than to overall high primary production.

7. Are there physiological and behavioral adaptations that make pack ice seals unusually efficient ecologically?

One potential reason for the abundance of seals in Antarctic pack ice ecosystems is that pack ice seals may have physiological and behavioral adaptations allowing a high efficiency of energy/carbon transfer to seals. This could result from low energy costs of maintenance involving metabolic adaptations such as lowering metabolic rate during diving, a short lactation period, and well-developed fasting abilities. Behavioral adaptations probably exploit the close juxtaposition of haul-out habitat (with associated potential reductions in energetic costs) and food resources.

8. How much photosynthetically-fixed carbon is transferred to the atmosphere by pack ice seals?

Seals may be a significant route by which carbon is lost from the marine ecosystem back to the atmosphere. Carbon flux models have been developed for the Southern Ocean (e.g., Huntley et al. 1991) and some have identified the potential importance of and the need for more information about carbon flux through air-breathing predators. An answer to this question could be obtained from a multidisciplinary approach which obtains information about seal distribution and abundance, behavior, tissue growth, body size, demography, and metabolism.

9. Are there physiological, condition, or behavioral indices in pack ice seals that could be used to appraise the Antarctic pack ice ecosystem through studies of its seal populations?

The use of indicator species is an accepted approach to ecosystem monitoring. The variables chosen to detect changes in predator species have often included characteristics such as reproductive success, growth rates, diet, survival rates, foraging effort, and population size. These may or may not be appropriate or practical for pack ice seals, and additional measures of ecosystem status and change should also be considered. Parameters such as weaning mass of seal pups and other condition indices have been useful in many wildlife studies, but it may also be possible to use such characteristics as disease and parasite incidence, levels of toxic substances in seal tissues, or blood chemistry.

SCIENTIFIC APPROACH

Field research activities

A coordinated program of field research is being developed to address the research questions outlined above. The principal needs for data collection activities are summarized in nine main topics; most of these individual activities provide information pertinent to more than one of the program's research questions (see Table 1). The basic approach for each of these topics is described briefly below. Additional background for these research topics can be found in the book, *Antarctic Seals: Research Methods and Techniques*, produced recently under the auspices of the SCAR Group of Specialists on Seals (Laws 1993). Descriptions of detailed methodologies to be used in the APIS Program will become available in 1994 as part of an in-depth companion document to the current prospectus.

1. Distribution, abundance, and species composition.

Estimation of seal abundance and its distribution in space and time is needed to address many critical research questions. Indeed, information on distribution and abundance is central to virtually all of the APIS Program's research questions. This topic's scientific importance and substantial logistic requirements warrant careful advance evaluation and planning to address: 1) survey design and feasibility of achieving adequate precision, 2) field procedures and choice of survey platform, and 3) comparability with previous surveys. Equal consideration must be given to estimating the abundance of seals visible on the ice and the actual proportion of seals hauled-out. The proportion hauled-out can be estimated via satellite- and radio-tagging (Bengtson & Stewart 1992), conventional tagging studies, fixed-site diurnal counts (Erickson et al. 1989), and by hydrophone surveys (Green & Burton 1988). Such efforts will be coordinated with studies of movement, activity patterns and dispersal.

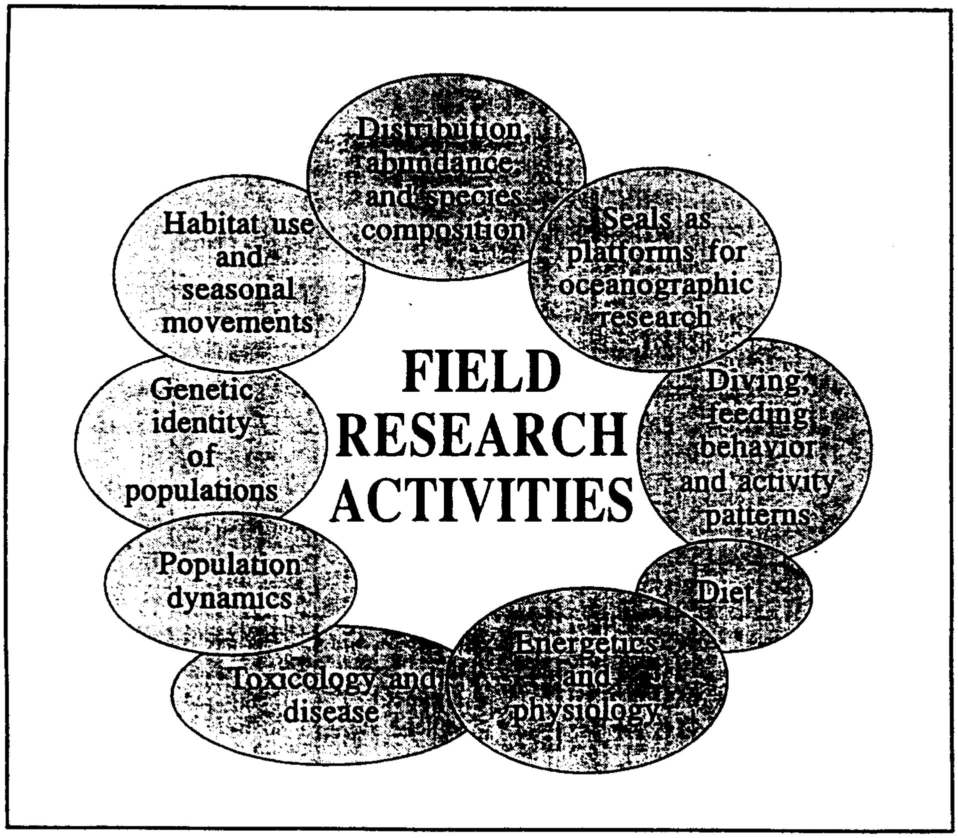
Previous surveys (Erickson & Hanson 1990) were conducted as strip transects, which assume that all animals hauled-out are seen within a strip of fixed width. Line transect methods (Buckland et al. 1993) could provide a conceptually simple but important extension, with estimates of sighting probability as a function of distance from the counting platform. Future surveys are planned to take advantage of this methodology, will be comparable to previous surveys, and could provide more accurate and precise estimates of abundance. Furthermore, the design of censuses needs to take into account the shifting distribution of pack ice during the survey period, and the degree to which such shifts may bias extrapolated estimates of seal densities. Ancillary variables other than distance (e.g., ice type, wind speed, bathymetry, oceanographic and biological observations), which may affect visibility and proportion of seals hauled-out, should be recorded during the survey. The choice of survey platform will depend on the area being surveyed; however, aerial surveys are likely to provide the best coverage of the pack ice. Whereas fixed-wing aircraft have a limited operational range from airstrips, helicopters operated from ice-strengthened ships provide extremely useful platforms for continent-wide surveys. Survey design and implementation must incorporate the highly variable nature and extent of the pack ice. Stratification and adaptive sampling (Thompson 1992) should be considered in the survey design. Results from previous surveys can be used to estimate expected variability and provide guidelines for potential survey stratifications. Emphasis should be given to standardizing observer training and data collection methods.

2. Genetic identity of populations.

For studies of carbon flux and to monitor long-term patterns of regional responses to environmental change, it is essential to identify whether or not seals in different geographic areas have discrete population identities. Molecular biology and genetic techniques, can be used, along with morphometric studies, to establish evolutionary relationships within and between Antarctic seal populations. Studies of DNA (both molecular and mitochondrial) and RNA characteristics are helpful in identifying populations and their inter-relatedness, comparing regional differences in genetic structures, and offering new insights into life history phenomena as well as population structure (e.g., relatedness among individuals within local regions). The procedures for considering differences in protein structures and probing sections of the DNA and/or RNA molecules through such techniques as polymerase chain reactions (PCR), northern and southern blottings, and *in situ* hybridization open many possibilities for obtaining information on relationships not previously available. Applying genetics and molecular biology techniques will also allow integration of knowledge developed on Antarctic seals with other species which are being investigated throughout the world.

3. Habitat use and seasonal movements.

The habitat use and seasonal movements of pack ice seals are most effectively investigated using satellite technology. Rapid advances in the field of electronic miniaturization has allowed development of complex instruments that can be carried on free-ranging seals and provide inter-seasonal comparisons. Satellite-linked instruments, designed to collect, process, and transmit data, have been successfully deployed on Antarctic pack ice seals for up to 10 months. In addition to relaying information on the location of



instrumented seals, data on the seals' behavior and ambient environmental conditions can also be obtained. Data from satellite telemetry of seals will be analyzed within the context of other environmental data obtained from remote sensing (e.g., sea ice distribution, ocean color, sea surface temperature) as well as regional data obtained from research vessels (e.g., structure of the water column, bathymetry, prey availability). Conventional tagging studies have also proven to be useful with some Antarctic species, and may be helpful under special circumstances.

4. Seals as platforms for oceanographic research.

Seals range widely within the Southern Ocean pack ice zone, an area which is relatively inaccessible to research ships, even those that are ice-strengthened. Seals also cover a wide range of depths during their foraging activities, involving repeated regular dives that may extend over periods of many hours (e.g., crabeater seals routinely dive repeatedly for approximately 15 hours, making about 10 dives per hour to over 100 m--and sometimes to over 400 m; Bengtson & Stewart 1992). The instrumentation specifically developed for studying seals' diving behavior continues to improve rapidly. Pack ice seals' large body size and behavior of regularly hauling out on ice floes make them ideal subjects for carrying instrument packages that communicate with satellites via radio. New electronic sensors connected to satellite-linked transmitters, glued to the backs of seals, could be developed and existing systems could be improved to provide physical and chemical oceanographers with hydrographic data on large scales and very cost-effectively. Position-fixing by satellite systems is precise. By using seals as free-ranging research platforms, it would be possible at all times of the year to measure temperature, salinity, light levels or other parameters in the water column, even when covered by sea ice.

5. Population dynamics.

Much of our knowledge about the population dynamics of the Antarctic pack ice seals has come from specimen material obtained from scientific collections. Important topics for future research focus on: 1) age at sexual maturity, 2) population age structure, 3) age-specific reproductive rates, and 4) age-specific survival rates. Research is needed on the relationships between these parameters and the environmental variables through which they are changed. A population of crabeater seals contains a unique record of past events covering decades; remote sensing techniques and long-term national research programs are only now starting to provide comparable time-series information with which to compare and interpret the population dynamics of pack ice seals. Using traditional methods in population dynamics studies requires the collection of seals. Although attempts are being made to develop new methods that reduce the need for killing seals (e.g., pulling teeth from living seals), non-lethal methods are not available or feasible at present in most cases. Undertaking collections will require consultation among national programs, interested organizations, and individual scientists to ensure optimal use of the specimen material and data obtained.

6. Diving, feeding behavior and activity patterns.

The main techniques available for studying diving and feeding behavior of free-ranging seals in the pack ice zone include time-depth recorders, stomach temperature and pH sensors, and jaw activity sensors. Sensors that collect data on swimming speed and direction are also needed to help quantify these behaviors. Sensors can be connected either to archival recorders, which must be recovered, or to satellite-linked transmitters. These devices make possible investigations of foraging effort and prey capture rates in various habitats (e.g., different ice types and cover, water depths, on shelf and offshore areas, pack ice and fast ice areas, thermal structures and light regimes in the water column). These techniques will help address comparisons of seal diving and feeding behavior related to different types of prey availability (i.e., benthic versus pelagic prey, concentrated versus dispersed). Time-depth recorders and their associated sensors can also be used to investigate haulout patterns and time budgets.

7. Diet.

Methods available to measure diet are: 1) analysis of stomach contents, 2) analysis of fecal samples, 3) serological analysis of fecal or stomach digests, and 4) analysis of lipid compositions of adipose tissues or the milk of seals in relation to the known distribution of lipid types in potential prey. In the case of pack ice seals, analysis of stomach contents probably provides the most satisfactory method of measuring diet because seals haul out on ice close to their food source and there is a good chance of obtaining representative samples of prey types before they have been digested. Analyses involve measurements of prey species composition by wet mass and the number of individuals and energy content represented by each prey species. Measurements of digestive efficiency are also required for prey items. Analysis of lipid composition allows investigating diet specialization in individual seals and across groups of seals, and therefore provides a more general measure of diet composition integrated over a longer time scale. The trophic position of pack ice seals and the trophic complexity of the pack ice ecosystem may be addressed with stable isotope studies of pack ice seals and their prey (e.g., Rau et al. 1992). Evaluation of the dietary habits of Antarctic seals also requires knowledge of the distribution and availability of prey. Indicators of the local availability of prey can be provided from analyses of the stomach and fecal contents of the various seal species and of other predators (e.g., birds, fish), and from specific assessments of prey distribution and abundance as determined by acoustic and other survey techniques.

8. Energetics and physiology.

Studies of energy/carbon flux require measurements of: 1) energy expenditures in relation to body size, environmental conditions, and level and type of activity, including the energetic costs of digestion, 2) growth rates and body composition in relation to age, sex and season, and 3) the major metabolic substrates (i.e., fats, proteins, carbohydrates) used by pack ice seals. The specific methods to be used in these studies are, respectively:

1) direct respirometry using open-circuit respirometers, indirect respirometry using doubly-labeled water, and indirect respirometry using heart rate in free-ranging seals;

2) morphometrics and stable- and radio-isotope dilution; and

3) estimation of the respiratory quotient during respirometry studies and the use of radio-labeled substrates to investigate significant metabolic pathways.

Table 2. Types and sources of complementary information that will be essential background for pack ice seal field research activities. CCAMLR=Convention for the Conservation of Antarctic Marine Living Resources; IWC=International Whaling Commission; SCAR=Scientific Committee on Antarctic Research; SOGLOBEC=Southern Ocean Global Ecosystem Dynamics; SOJGOFS=Southern Ocean Joint Global Ocean Flux Studies; CEMP=CCAMLR Ecosystem Monitoring Program; GLOCHANT=SCAR Global Change and the Antarctic Program.

Research questions	Data needs complementary to seal field research activities									Sources of complementary data						
							Oceanography									
	Sea ice	Climate	Primary production	Prey	Competitors	Fisheries data	Biological	Chemical	Physical	CCAMLR	IWC	SCAR	SOGLOBEC	SOJGOFS	CEMP	GLOCHANT
What are the causes and scale of variation in the distribution and abundance of pack ice seals?	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
Has ecological partitioning contributed to crabeater seals being more abundant than other pinniped species; if so, why?	X		X	X	X	X	X	X	X	X	X	X	X			
Are there more seals per unit of primary production in the Antarctic than in other regions; if so, why?	X		X				X			X		X	X	X	X	
Why do selected life history parameters in pack ice seals appear to fluctuate in a periodic fashion?	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Why have population parameters and observed densities of seals changed over the past 30 years?	X	X		X	X	X	X			X	X	X			X	X
How have seal diets and foraging strategies adapted to optimize utilization of their food resources?			X	X	X		X			X	X	X	X		X	
Are there physiological and behavioral adaptations that make pack ice seals unusually efficient ecologically?	X		X	X	X		X			X	X	X	X		X	
How much photosynthetically-fixed carbon is transferred to the atmosphere by pack ice seals?			X		X		X	X	X			X	X	X		
Are there physiological, condition, or behavioral indices in pack ice seals that could be used to appraise the Antarctic pack ice ecosystem through studies of its seal populations?	X	X	X	X		X	X		X	X		X	X		X	X

Such studies have been undertaken in the past on other species at shore-based facilities; future ship-based studies in the pack ice may involve containerized laboratories.

9. Toxicology and disease.

As long-lived bio-accumulators of certain compounds within Antarctic marine ecosystems, pack ice seals are excellent subjects for studying the long-term changes in the levels of organochlorines and heavy metals present in the Antarctic. Protocols for the collection, storage and analysis of pinniped tissue samples have been developed by a number of institutions (e.g., Alaska Department of Fish and Game, Swedish Museum of Natural History, Oslo College of Veterinary Medicine). Agreed protocols will need to be incorporated into the APIS Program. Necropsy analysis of individuals will also be used to detect patterns of disease, including analyses for the range of pathogens known to cause zoonoses in marine mammals (e.g., Bengtson et al. 1991). Presence and types of parasites in samples collected from seals may provide clues into the general health of seals.

Liaison with other Antarctic research programs

To complement the data obtained through field research focusing directly on seals, a variety of data pertaining to the seals' environment will be needed (e.g., sea ice type and distribution, prey availability, oceanographic conditions, and the status of other ecosystem components). The APIS Program intends to develop efficient liaisons with other Antarctic research initiatives, so that mutually beneficial communication and data exchanges can be ensured. Table 2 describes the types and potential sources of some of the complementary data needed by this program.

Analyses and modeling

It is well established that in scientific endeavors, models are very important structures that contribute, at a minimum, to the sequence logic of addressing research priorities, for predicting linkages in data collection programs, and for investigating possible cause/effect relationships once sufficient data become available. This program plans to use models in the initial stages to guide thinking, outline hypotheses, and ensure proper linkages between various components within the research program. It is envisioned that these efforts will eventually be extended to larger model structures providing insight into the linkages among environmental events, species interactions, and population responses.

LOGISTICS AND TIMING

Field research schedule

Although it is recognized that many of the research topics outlined in this prospectus will require long-term studies, an initial program focused over a five-year period is proposed. Priority field research activities would be undertaken during the period running from the 1995/96 through the 1999/2000 austral summer seasons. In defining this target period, it is recognized that some pack ice seal studies are already underway. The continuation of these studies is strongly encouraged; the information that they are generating will strengthen the planning and experimental design process for the broader program.

Within the five-year program period, the 1997/98 and 1998/99 seasons have been identified as the target years when synoptic surveys and experiments requiring multi-ship and multi-aircraft logistic support should be emphasized. In addition, it will be important to ensure that data are obtained during the austral winter, a time when little pack ice seal research has been conducted in the past.

The timing requirements for the various research projects outlined in this program will differ depending on the topic being studied and the amount of past work already completed. Some projects could be undertaken on an opportunistic basis in concert with other projects if neither the month nor year when data are collected is particularly important. Others, however, require successive year data, so once the project is initiated, it should continue for at least three years. Still other projects require significant logistic support for data from successive years within a short intra-seasonal time frame.

The projects that may be executed without reference to a specific year include: 1) the genetic identity of populations, 2) diet, 3) energetics and physiology, and 4) toxicology and disease studies. In general, these programs can be carried out at any time throughout the program's duration, although it would be useful if studies of the genetic identity of population studies could be conducted early on in the program so that this information can be used in planning other research activities. The time of the year when these programs should be executed is fairly flexible, but the studies on diet should be focused, if possible, in the austral winter from May to August because of the paucity of data during that time. Furthermore, the energetics and physiology work should be conducted in September to November during the reproductive period, when energetic studies are particularly useful.

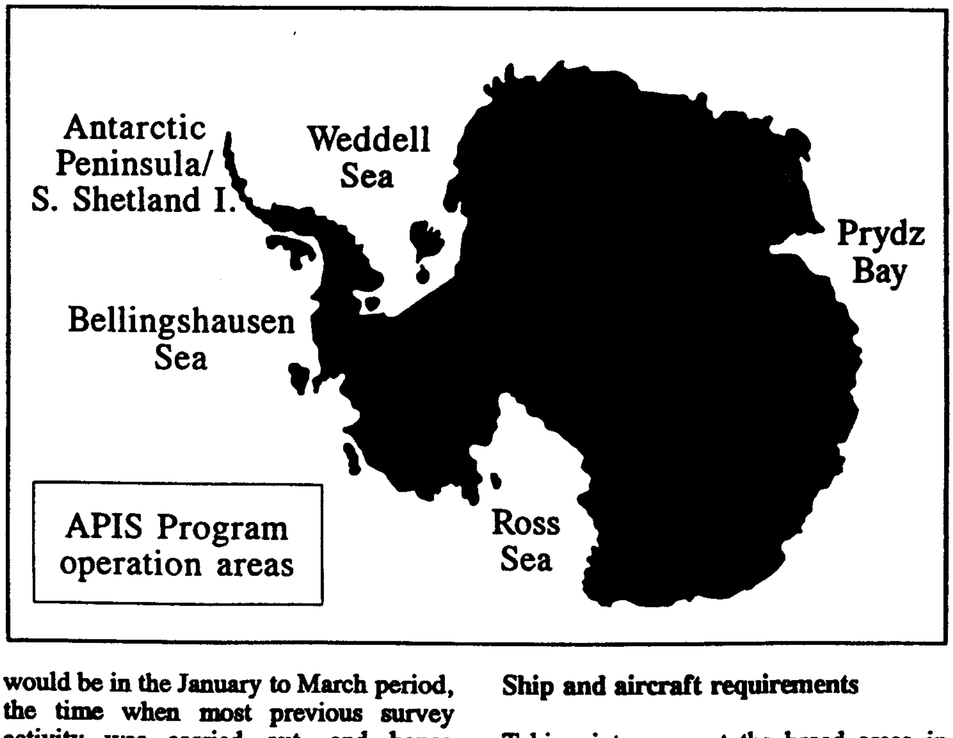
The activities that require comparisons of successive year data include studies of: 1) population dynamics, 2) diving and feeding behavior, and 3) activity patterns. It is particularly important that successive year data be collected for these programs, since the environmental conditions present in one year often influence what happens during the following year. For example, a particularly poor reproductive season in one year would have considerable influence upon the age structure of the population the following year. Thus, it is very desirable that these research activities be sequenced on an annual basis. The priority months for these studies are not particularly critical and they could be carried out throughout the annual cycle. However, surveys of age composition need to be conducted during the pupping season, in the September to November time frame, since it would be possible, at this time, to obtain adult/pup ratios during survey activities. These data are valuable for comparisons with annual environmental data such as ice cover and ocean current patterns.

Finally, there are activities that require data from successive years in specific months as well as large scale logistic support. These research activities include studies of distribution and abundance and species composition, studies of habitat use and seasonal movements, and investigations that will involve seals as platforms for oceanographic research. All of these programs require some type of multi-ship and multi-aircraft support in order that comparable studies can be simultaneously undertaken in several areas of the Antarctic. The priority months for studies of the distribution, abundance, and species composition would be in the January to March period, the time when most previous survey activity was carried out, and hence comparison to past data bases would be most feasible. The other research activities that require this type of logistic support could be carried out at any time of the annual cycle or could be executed within the time frame for studies of distribution, abundance, and species composition.

Areas of operation

Although the questions addressed by this research initiative are relevant in all of the circumpolar pack ice areas around Antarctica, research efforts are likely to be most effective if they are focused in targeted study regions that are representative of continent-wide conditions. Several factors were considered in selecting the study regions: 1) coordination and integration with other Antarctic research programs (e.g., CEMP, SO-GLOBEC, SO-JGOFS), 2) sites where long-term data bases already exist (facilitating comparisons of past and future data), and 3) logistic convenience in relation to research bases and vessel operations areas. The APIS Program will focus on the following study regions:

1) the Bellingshausen Sea;
2) the Antarctic Peninsula and South Shetland Islands area;
3) the Weddell Sea;
4) the Prydz Bay area; and
5) the Ross Sea.



Ship and aircraft requirements

Taking into account the broad areas in which operations are needed during the Antarctic pack ice seal censuses, an international effort is clearly needed. It is hoped that those countries which have suitable ship resources will participate actively during this multinational program. Similarly, significant aircraft resources will be required, operated from ice-strengthened ships as well as from land-based facilities.

The program components requiring multi-ship pack ice support are proposed to be carried out during the austral summer season. Of course, it is recognized that differences in the extension of pack ice in relation to continental shelf areas will require adjustments in the timing of ship and aircraft operations. Near the north/western Antarctic Peninsula, where sea ice cover is usually greatly diminished during summer, it would be desirable to operate as early as possible, and then continue scientific activities through spring as the pack ice recedes.

Cooperation among national programs

The broad geographical extent and temporal distribution of the planned tasks require that national programs cooperate to share logistics and research opportunities. This cooperation is essential in the field of logistic operations and is imperative to achieving the objectives of the APIS Program. Where national programs are active in the same areas or have related scientific activities, it is suggested that they endeavor to complement each other's efforts in order to make the logistic and science activities more efficient.

COORDINATION

Planning and communications

For this program to be successful, close liaison and extensive coordination will be required. Liaison with many other scientific bodies such as other SCAR Groups of Specialists and Working Groups, as well as other bodies such as CCAMLR and SO-GLOBEC, will be essential. Coordination is necessary to ensure comparability of research plans that have mutual objectives, data collection procedures, and exchanges of data.

A steering committee for the APIS Program will be formed from members of the SCAR Group of Specialists on Seals to assist in international coordination of science objectives and logistics. To ensure close liaison with planning at the national program level, COMNAP will be invited to nominate a member of the steering committee.

The proper coordination of data collection from the various parts of this program will largely determine the eventual success in answering the research questions posed. Each national program will be encouraged to take advantage of their particular expertise and national priorities, focusing on specific research questions and their linkages to other components of the overall pack ice seal research program. Comparative analyses will, of necessity, involve coordination among scientists from various national programs and thus periodic workshops will be needed.

Funding

If it is to be successful, the pack ice seal program outlined in this prospectus will require a greater level of funding than Antarctic seal research has received in the past. The Group of Specialists on Seals plans to seek financial support to supplement resources made available directly to investigators from national programs. The purpose of these additional funds will be:

1) to bring participants to international meetings and workshops for planning, implementation, and analyses;

2) for a part-time secretary to help coordinate activities and facilitate communications, including data handling and management; and

3) for special needs such as procuring instrumentation.

The Group of Specialists on Seals intends to seek additional funding from outside SCAR for these activities. A fund should be established to be used for these purposes, with contributions being sought from funding bodies such as foundations, environmental organizations, and commercial companies. It is intended that individual scientists will approach their own national programs for support of their individual research projects, which contribute to the wider program framework and objectives.

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The SCAR Group of Specialists on Seals held a workshop from 4-6 May 1993 to discuss priority pack ice seal research topics and to develop a plan for a coordinated, multi-national research initiative. The workshop was held at the University of Minnesota, St. Paul, Minnesota, USA, and was made possible through the financial support of SCAR, CCAMLR, and the U.S. National Science Foundation. The workshop produced this prospectus, which will be followed-up with a more detailed program proposal during 1994. The participants of the May, 1993, workshop included:

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